1944

The use of carbon dioxide for dislodging coal in mines

Durward Rice Schooler

THE USE OF CARBON DIOXIDE

FOR

DISLODGING COAL IN MINES

BY

DURWARD RICE SCHOOLER

A

THESIS

Submitted to the Faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in fulfillment of the work required for the

Degree of

ENGINEER OF MINES

Rolla, Missouri

1944

Approved by ______________________
Professor of Mining

ACKNOWLEDGMENT

For valuable co-operation and information in the preparation of this paper, the writer is indebted to Mr. John Bell, Executive Vice-President, Cardox Corporation, 307 North Michigan Avenue, Chicago, Illinois; to Mr. J. M. Johnston, General Manager, Bell & Zoller Coal and Mining Company, Zeigler, Illinois; and to the United States Bureau of Mines, Rolla, Missouri.

FOREWORD

The coal mining industry, prior to 1940, was undoubtedly facing a period when operating economies and efficient utilization of labor, machines and modern practices were more necessary than ever before. With its markets definitely threatened by other sources of heat and power produced with a minimum of labor, "Coal" had to exert every effort to secure the lowest possible production cost and also to produce a more satisfactory product with greater safety to men and mines.

Blasting, or breaking the coal from the coal face, is one operation in the mining of coal that has an important bearing on both the cost of production and the quality of the coal produced. Blasting also presents a major problem for the safety of the men and for the protection of the mine itself.

Prior to the 19th Century, all coal was dislodged by the use of a sledge, wedge, pick and crowbar. In the early part of the 19th Century, miners began to use black powder to "shoot" the face. By shooting the face, production was increased and costs were lowered. However, much of the advantage gained was offset by the danger involved, to men and mines, by the use of black powder. Its long, hot flame ignited gas and coal dust in many mines with disastrous results.

In 1907, the United States Bureau of Mines was created to promote mine safety. Exhaustive tests were made on different explosives to determine the hazards involved in their use. The term "permissible" was coined to designate a type of explosive which was approved for use in dusty and gaseous coal mines. The safer and more desirable characteristic of a permissible explosive is that the rate of detonation is so rapid it is less liable to ignite gas or coal dust than black powder. But this rapid discharge, which minimizes ignition of dust and gas, results in a sudden shock that shatters the coal. Thus, while permissibles are safer than black powder, their effect on the coal structure of the marketable coal is much worse.

"Cushioned" shooting with permissible explosives has been tried, and in some cases has shown an improvement in the grades of coal produced. However, all explosives are just what their name implies, explosive, and the coal broken down by them is caused by an explosive charge with the resultant shock.

Modern mining demands a method of breaking down coal that is not only safe, but economical as well. This method must be slow enough to retain the natural lumpy structure of the coal and permit high realization. It must be gentle enough to bring down the coal without producing minute shatter-cracks in the coal. It must discharge without smoke or noxious fumes, so that an unsafe atmosphere is not created in the working places. It must roll the coal free from the face, so that it may be easily loaded by mechanical loaders.

Many attempts have been made, with various methods, to invent a method of breaking down coal that would fulfill the requirements stated above. In 1924 or 1925, three coal mining men of southern Illinois -- a chemist, an electrical engineer and a mine operator -- conceived the idea of a non-explosive cartridge utilizing the force of expanding carbon dioxide to break down coal at the working face. They sought a medium that would be as safe, or even safer, than permissible explosives, yet which would preserve the inherently firm structure of the coal and produce less fine coal than any other type of explosive.

There followed several years of extensive research and experimentation in the southern Illinois coal fields. Various sizes of cartridges, pressures and heating elements were tried and discarded before a workable unit was evolved. In 1927, the Safety Mining Company was formed and took over all patents for the method. The trade name of CARDOX was given the method and further experimentation with cartridges, method of shooting and co-ordinating of mining methods with CARDOX shooting was carried on. The final development was started and carried on for several years at the No. 5 mine of the Centralia Coal Company, at Centralia, Illinois, and at the No.1 mine of the Bell & Zoller Coal and Mining Company, at Zeigler, Illinois. The writer was acting as Mining Engineer for these companies at that time and assisted in the development of CARDOX at these properties.

This paper deals with an explanation of the theory and mechanics of the medium and the construction of the cartridge used in the CARDOX method. Some of the details of experimentation at Centralia and Zeigler, Illinois, and the system of cutting, drilling and shooting with CARDOX are explained. Also, the mine layout and method of distribution of shells and accounting on cartridges as used by the Bell & Zoller Coal and Mining Company, at Zeigler, Illinois is herein dealt with, as well as a list of safety rules for handling CARDOX.

LIST OF TABLES

LIST OF ILLUSTRATIONS

CONTENTS

CARDOX METHOD OF COAL MINING

The Cardox method of mining coal is essentially that of dislodging coal with carbon dioxide under precisely predetermined pressure. (See chart). Its physical basis is simply that this inert, non-poisonous gas, kept under pressure, expands when liberated in a drill hole with force sufficient to break down the coal. It operates without smoke, flame or noxious fumes.

Carbon dioxide was selected as the ideal gas for Cardox mining because it is inert and will not burn or support combustion. Equally important, carbon dioxide is non-poisonous. Its physical characteristics are favorable for breaking down coal and it is easy to procure.

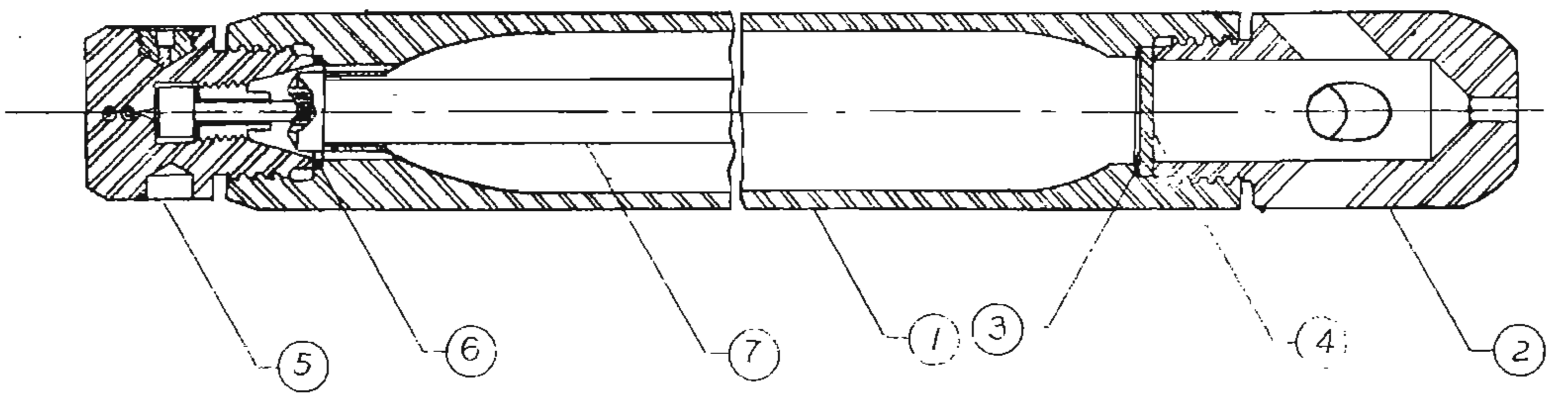
The carbon dioxide is compressed in a tube, or shell, inserted in a hole drilled in the coal face and the shell discharged, thereby dislodging the coal.

The Cardox tubes, or shells, which are made in several sizes, ranging from two to three inches in diameter, weigh from ten to forty lbs. and consist of hollow tubes forged of chrome-molybdenum steel, capable of withstanding internal pressures up to 40,000 lbs. per square inch. Into one end of the tube is threaded the charging cap, and into the other end is threaded the discharge cap. (See Figure 1.)

The charging cap houses, in addition to the charging valve, two electric terminals for connecting the shot firing cables to an electric squib, or match, in the heater element.

The discharge cap is equipped with angle parts through which the expanding carbon dioxide is released at discharge. These parts are constructed on an angle, so that they hold the shell, or tube, to the back of the drill hole when the shell is discharged.

Sketch of Shell



PARTS LIST

IT.	DESCRIPTION	DRAWING	NO
1	SHELL BODY	CB-155	1
2	" DISCHARGE CAP	CB-247	1
3	" " GASKET	CA-340	1
4	" DISC	CA-339	1
5	" TOP ASSEMBLY	BM-272-C	1
6	" " GASKET	CA-315	1
7	" HEATER		1

FIGURE 1

CB-83 REDRAWN WITH PERMISSION OF CARDOX CO.

A soft steel shearing disc is held firmly over the open end of the shell by the discharge cap. This disc seals the liquid carbon dioxide in the shell until the predetermined discharge pressure is reached.

The shell is assembled and charged as follows: The heater element, containing the electric squib, is inserted in the charging end of the tube with the electric squib in contact with the terminals in the cap. A soft steel disc, varying in thickness according to pressure desired, is placed over the opposite end of the tube and the discharge cap is screwed on, holding the disc firmly in place. Liquid carbon dioxide is then pumped into the shell and the shell is then ready for discharging.

When current is applied to the terminals in the charging cap, the electric squib, or match, causes a chemical reaction of the chemicals in the heater and sufficient heat is generated to gasify the carbon dioxide instantly, increasing its pressure within the tube. As the gases in the tube reach the predetermined discharge pressure, the shearing disc gives way, and the gas is released through the ports.

Discharge pressures of Cardox tubes, which can be released by a fraction of an ampere at two or three volts, range from 10,000 to 22,000 lbs. per square inch.

The discharge in no way injures the Cardox shell. The only part that has to be replaced is the shearing disc, which is renewed when the shell is recharged. After the coal is broken down, the empty shells are recovered from the fall of coal and returned to the charging plant for re-charging.

The heating element, or charcoal heater, used to generate the heat in the shell is made with a stoichiometric mixture of potassium perchlorate and charcoal. The following proportions are used: thirteen per cent (13%) charcoal, one-half to one per cent (1/2 to 1%) oil, eighty-six and one-half per cent (86½%) potassium perchlorate.

The charcoal used must all pass through a 200-mesh screen. The perchlorate ranges between 40-mesh and 200-mesh.

The heating elements containing the electric squib, or match, are rolled from standard craft paper by automatic tube rolling machines. The burning compound is mixed and tamped in the paper tubes by mechanical tampers. The heating elements are manufactured by the Safety Mining Company in their own plants and shipped ready for use in the shells.

The liquid carbon dioxide is stored at the mine in a Cardox low pressure storage tank having a capacity of four tons, or in a battery of standard fifty-lb. high pressure cylinders, depending upon the type of charging plant installed. The carbon dioxide is delivered to the various mines from central distribution plants by trucks owned and operated by the Cardox Corporation. Figure 2 shows a general arrangement of a charging plant for a mine. In many mining districts the Cardox Corporation maintains a central charging plant where the shells are charged and delivered by truck to the various mines in that district, ready for use. This system is now used in the southern Illinois district in which the writer assisted in the development of this method of blasting. The central charging station is located at Benton, Illinois and serves mines located at Zeigler, Valier, Royalton,

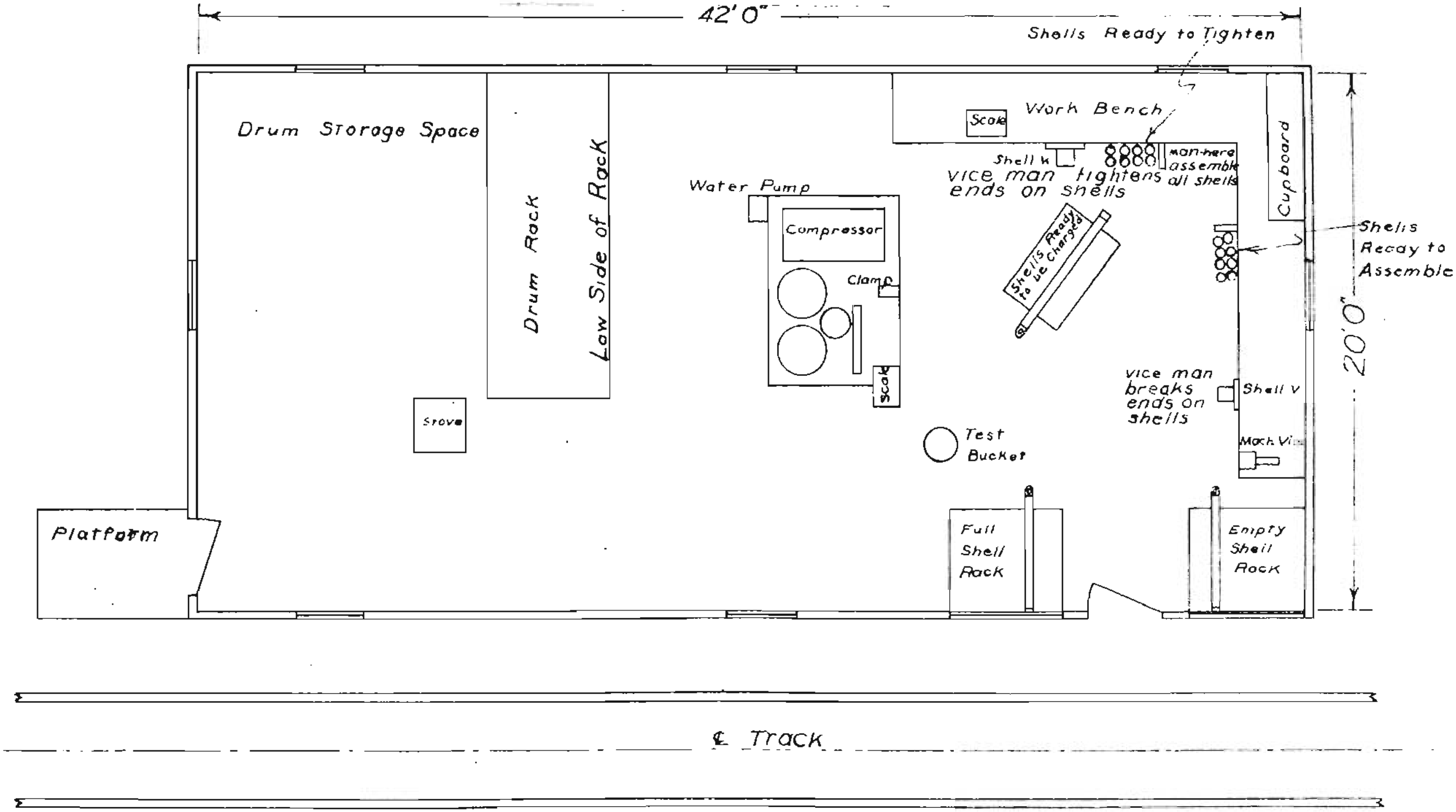


FIGURE 2

Layout
of Three or Four Man
Junior Charging Plant

Scale $\frac{3}{16}$" = 1' 0"

West Frankfort, Herrin and all other mines in the southern Illinois district.

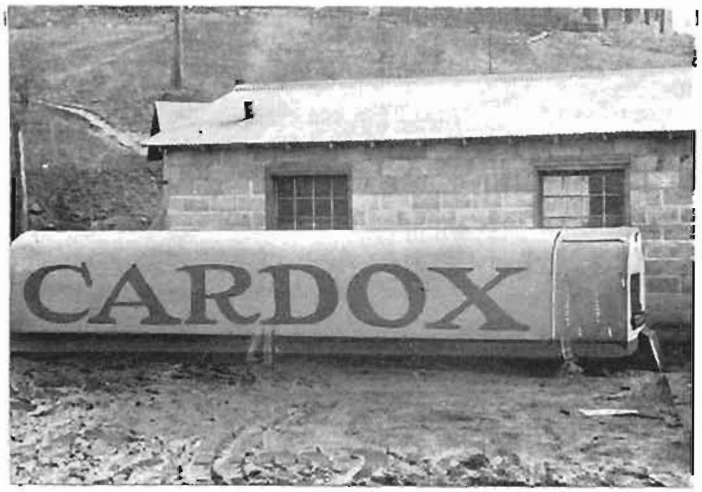
Two factors determine the extent of the working force of Cardox — the volume of carbon dioxide and the release pressure. The release pressure determines the breaking force of the blow delivered, while the volume of carbon dioxide determines the radius of action of the expanding gases. Table I gives pertinent data as to the various sizes of tubes, or shells, the volume of carbon dioxide for each model, the range of shearing discs for each model, etc.

Perhaps an explanation of this table will help to clarify several of the headings. The No. 1 column, entitled "Tubes", gives the model number of the tube, or shell, and the numbers have a certain significance. For example, "2-50" means two inches in diameter and fifty cubic inches volume; "2-80", two inches in diameter and eighty cubic inches volume, etc.

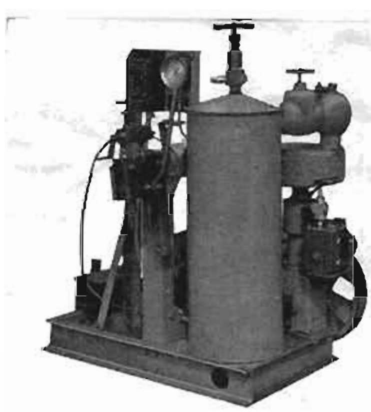
Column No.2 gives the shear diameter of the shearing disc. Columns 3 and 4 give the gage and disc thickness of the shearing disc in inches. The breaking force is regulated by the thickness of this disc. Columns 5, 6 & 7 list the internal pressures or hydraulic pressures to shear the various size discs.

Column 8 shows the "Recommended Charcoal Heaters." However, the Cardox Corporation has improved the efficiency of the heaters and a smaller heater than the one listed for specific models may now be used.

Column 9 indicates the maximum size heater which has been approved for use in the various shells by the Bureau of Mines. Columns 10 and 11 require no comment.



At the mines the liquid Carbon dioxide is stored in a Cardox pressure storage tank having a capacity of 4 tons or a battery of 50-lb. high pressure storage cylinders are refilled, thus insuring an ample supply of carbon dioxide at all times.



Cardox low pressure charging plant.

Figure 3

The seam is undercut in the usual manner.

Figure 4

Table I

CARDOX CORPORATION

Permissible Combinations and Pertinent Data CARDOX Cartidges

1 Model No. of Shell	2 Shear Dia.	3 Disc Gage	4 Disc Thickness	5 Hydraulic Pressure to Shear Disc Minimum By B. Of M.	6 Normal	7 Maximum Cardox	8 Recommended Charcoal Heater :- Grams
2-50	1-1/16"	16	.062	8,000	10,000	12,000	40
		14	.078	10,000	12,000	14,000	45
		12	.109	13,000	15,000	17,500	60
		10	.140	17,000	19,000	22,000	100
2-80	1-1/16"	16	.062	8,000	10,000	12,000	60
		14	.078	10,000	12,000	14,000	80
		12	.109	13,000	15,000	17,500	100
		10	.140	17,000	19,000	22,000	110
2-100	1-1/16"	14	.078	10,000	12,000	14,000	80
		12	.109	13,000	15,000	17,500	100
		10	.140	17,000	19,000	22,000	110
231-130	1-5/16"	12	.109	12,000	14,000	16,000	100
		10	.140	16,000	18,000	20,000	140
		8	.172	18,000	20,000	22,000	180
*D-100	1-1/4"	12	.109	16,000	17,500	19,000	160
		10	.140	21,000	22,500	24,000	180
		8	.172	25,000	26,500	28,000	200
D-100	1-7/16"	12	.109	11,000	13,500	15,000	160
		10	.140	17,000	18,500	20,000	180
		8	.172	21,000	23,000	25,000	200
3-200	1-3/4"	12	.109	10,000	12,000	13,000	180
		10	.140	13,000	15,000	17,000	200
		8	.172	17,000	18,000	20,000	220

* = Obsolete, but quite a few in service

:- = Improvements have been made on heaters listed

Table I (contd.)

CARDOX CORPORATION

Permissible Combinations and Pertinent Data CARDOX Cartridges

9 Maximum Heater Permissible Grams	10 Recommended Normal Charge CO_2 Ounces	11 Minimum Heater for Shear with Normal CO_2 Grams	12 Min. CO_2 for Shear with Heater in Column 8 Ounces	13 Overall Assembled Length Inches
80	24	25	-	34-3/4"
80	24	30	16	
100	24	35	16	
110	24	50		
80	36	35	23	46-3/4"
110	36	40	22	
110	36	60	24	
110	36	80	26	
110	48	45	27	58-3/4"
110	48	60	38	
110	48	80	39	
140	64	50	50	59-5/8"
160	64	70	46	
180	64	100		
180	48		26	47-3/4"
200	48		31½	
200	48	140	33	
160	48	60	23	47-3/4"
200	48	80	28	
200	48		30	
220	96	90	64	53
220	96	110	73	
220	96	160	77	

Column 12 indicates the minimum quantity of gas that can be expected to shear the disc with the amount of heater indicated in Column 8. Column 13 gives the overall length of the assembled shell.

The following is a reprint from the United States Bureau of Mines Report of Investigations, R.I.3084, dealing with "The Propulsive Strength and Rate of Pressure Development of the Cardox Blasting Device." It is by N.A.Tolch, Associate Mining Engineer, U.S.Bureau of Mines, Pittsburgh Experiment Station, Pittsburgh, Pa. and G. St. J. Perrott, Superintendent, U.S.Bureau of Mines, Pittsburgh Experiment Station, Pittsburgh, Pa.:

(In this paper the "propulsive strength" or "strength" is defined as the relative propulsive or heaving effect as measured by the Bureau of Mines ballistic pendulum.)

(The model "G" shell used in this experiment is now obsolete. The present models have many improvements and fewer parts than the model "G." However, the Bureau's test, together with tests carried on by the Cardox Corporation, give accurate information on results obtainable with different combinations of carbon dioxide, heater and disc.)

R. I. 3084
April, 1931.

REPORT OF INVESTIGATIONS

DEPARTMENT OF COMMERCE - BUREAU OF MINES

==================================

THE PROPULSIVE STRENGTH AND RATE OF PRESSURE DEVELOPMENT OF THE CARDOX BLASTING DEVICE

By N. A. Tolch and G. St. J. Perrott

PURPOSE OF TESTS

The propulsive strength developed by the Cardox blasting device depends on the thickness of disk, weight of heater element, and weight of carbon dioxide charge. It might be supposed that the maximum weight of carbon dioxide that can be charged into the shell should give the greatest strength. However, according to the ballistic pendulum, the maximum weight of carbon dioxide with certain conditions of heater and disk has less propulsive strength than a smaller charge; in one condition of test a loss of 39 per cent in propulsive strength was noted. It is therefore of interest to study the effect of the variables that determine the strength of Cardox.

ACKNOWLEDGMENT

Grateful acknowledgment is made to A. B. Coates, associate mechanical engineer, who developed the testing method for measuring pressures in the Cardox shell.

DESCRIPTION OF DEVICE

The Cardox blasting device as fully described by the bureau in Report of Investigations 2920 (1929), consists essentially of hollow-steel shell, cylindrical in shape, an electrode, valve assembly, shearing disk, and discharge cap. The shell is prepared for use by inserting a heater element, closing the open end with a shearing disk, and screwing in place the discharge cap. The charge of carbon dioxide enters the shell through the electrode.

The heater element is fired by an electric igniter of the match-head type. The heat released by the heater element completely gasifies the carbon dioxide and raises the pressure of the gas until it is enough to shear the disk.

Three models of Cardox blasting devices have been approved as permissible; Models A, AA, and G. The Model A and the Model AA shells are essentially the same except for certain differences in firing design. The Model G shell is somewhat simpler in design than the Model A shell and is considerably lighter in weight. It is 80.6 centimeters (31-3/4 inches) in length, 7.6 centimeters (3 inches) in diameter, weighs 18.0 kilograms (39.5 pounds), and has a free volume, with heater inserted, of 1.38 liters (84.18 cubic inches).

PROCEDURE OF TESTS

Briefly, an explosive under test is fired in a steel cannon into a mortar weighing 31,000 pounds, suspended from knife edges; the resultant swing is a measure of the propulsive or heaving effect of the explosive under test. All strength tests are compared to Pittsburgh Testing Station 40 per cent straight dynamite, which is always manufactured on the same formula.

In testing the Cardox blasting device, a curve was first determined to show the swing of the ballistic pendulum for a given charge of the standard dynamite mentioned. The Cardox shell was then discharged into the mortar and the average swing by three or more trials noted. The strength of a particular condition of charging is expressed in grams of the standard dynamite; a particular condition of charging as to thickness of disk, weight of heater, and weight of carbon dioxide will give the same swing, or is equivalent to a certain weight of the standard dynamite, in the ballistic pendulum.

In making ballistic-pendulum tests with Cardox, the four side-discharge holes of the discharge cap are plugged and a hole is drilled centrally in the end of the cap along the longitudinal axis of the shell. By this method the gases are discharged in a forward direction rather than a side direction.

The tests mentioned in this paper, in greater part, have been made with the Model G shell. The conditions of charge tested in the ballistic pendulum have also been tested in the gallery and found safe for use in gassy and dusty coal mines.

RESULTS OF TESTS

Table 1 lists the results of ballistic-pendulum tests with the Model G shell. The average swing and the equivalent strength in grams of the standard dynamite are given for each condition of charge.

Table 1.

Results of ballistic-pendulum tests with Cardox Model G Shell

Disk		Heater,	Carbon dioxide		Average swing,	Equivalent of Pittsburgh Testing Station 40 per cent straight dynamite, grams
Milli-meters	In.	grams	Grams	Pounds	centi-meters	
3.2	1/8	100	910	2	7.50	197
3.2	1/8	100	1080	2-3/8	8.82	233
3.2	1/8	100	1250	2-3/4	6.35	165
3.2	1/8	125	910	2	9.20	245
3.2	1/8	125	1080	2-3/8	9.94	265
3.2	1/8	125	1250	2-3/4	6.61	172
3.2	1/8	140	910	2	10.62	285
3.2	1/8	140	1080	2-3/8	9.40	253
3.2	1/8	140	1250	2-3/4	6.63	173
4.8	3/16	100	1250	2-3/4	7.32	192
4.8	3/16	125	1250	2-3/4	8.85	235
4.8	3/16	140	1250	2-3/4	8.79	232
6.4	1/4	140	1250	2-3/4	10.35	278
6.4	1/4	160	1020	2-1/4	12.60	347
6.4	1/4	160	1135	2-1/2	11.39	310
6.4	1/4	160	1250	2-3/4	9.81	262
7.9	5/16	160	1250	2-3/4	12.47	3.42

Effect of Quantity of Carbon-Dioxide Charge

With 6.4 millimeter (1/4-inch) shearing disks and 160-gram heaters the strength drops off rapidly with increased carbon-dioxide charge. The loss in propulsive strength is 24 per cent when the charge is increased from 1,020 grams (2-1/4 pounds) to 1,250 grams (2-3/4 pounds). With 3.2 millimeter (1/8-inch) disks and either 100 or 125 grams heaters, the maximum propulsive strength occurs with neither the minimum or maximum weight of carbon dioxide, but with an intermediate weight of carbon dioxide. With 3.2 millimeter (1/8-inch) disks and 140-gram heaters, the minimum weight of carbon dioxide tested gave the greatest propulsive strength.

Effect of Quantity of Heater Material

An increase in the weight of heater material should result in greater developed propulsive strength because of greater available heat energy. With 3.2-millimeter (1/8-inch) disks and 910 grams (2 pounds) of carbon dioxide, the strength increases with increase in heater. However, with the capacity charge of 1,250 grams (2-3/4 pounds) little difference is noted in propulsive strength whether fired with 100, 125, or 140 gram heaters.

Effect of Thickness of Disk

The data in Table 1 show that the propulsive strength is greater with increase in thickness of disk.

It should be noted that the comparable data on the effect of thickness of disk were all obtained with the maximum carbon-dioxide capacity of the shell (1,250 grams), with which charge the propulsive strength is different from that of smaller weights of carbon dioxide. The effect of thickness of disk might therefore be different if studied with smaller weights of carbon dioxide.

Effect of Sized Sodium Chlorate on Propulsive Strength

Table 2 lists the results of tests made to determine the effect of sizing the particles of sodium chlorate in the heater element. The Model A shell was used with 160-gram heaters, 3.2-millimeter (1/8-in.) disks, and 1,700 grams (3-3/4 pounds) of carbon dioxide. The heaters were made up according to the basic formula.

Table 2.
Effect of sized sodium chlorate on propulsive strength

Grain size, mesh	Average swing, centimeters	Equivalent of Pittsburgh Testing Station 40% straight dynamite, grams
20 to 30	9.61	255
30 to 40	11.19	305
40 to 60	11.53	313
80 to 100	12.69	350
100 to 120	12.87	358
120 to 140	11.98	327

These results would indicate that the smaller grain sizes of sodium chlorate give greater propulsive strength. However, a limit was reached at a size of 100 to 120 mesh beyond which the propulsive strength decreased slightly.

RATE OF PRESSURE DEVELOPMENT OF THE CARDOX MODEL G SHELL

The method of test is similar in principle to that used in obtaining the rate of pressure development of black blasting powder, except that the Cardox shell itself formed the explosion chamber instead of the Bichel gage.

The apparatus consists essentially of the Cardox Model G shell, a pressure-indicating device, a revolving drum, a tachometer, and two induction coils.

The pressure-indicating device consists of a piston, spring, and lever arm, a given movement of the piston producing a proportional deflection of the lever arm. The value of the lever arm movement is obtained by calibrating the device against known pressures. When the shell is discharged, the rising pressure forces the piston out against the pressure of the spring deflecting the lever arm, whose movements are traced on the soot-covered surface of a revolving drum. A record is thus obtained of the rate of pressure development and the magnitude of the pressure.

The primary of an induction coil is placed in series with the electric match head. When the match head is fired, the primary circuit is broken, producing current in the secondary and a spark on the revolving drum, thereby recording the time at which the match head in the heater is fired. The primary of a second induction coil is placed in series with an electric circuit running through the discharge cap of the shell. When the disk is sheared the primary circuit is broken, producing current in the secondary and a spark on the revolving drum.

With this apparatus a record should be obtained of the time at which the match head was fired, the time at which the pressure starts to rise, the rate of pressure development, the magnitude of the pressure, and the time and pressure at which the disk shears. In actual testing it was found necessary to obtain these data in two stages. In shots in which the disk sheared, the shell movement from the force of the explosion was sufficient to throw the pressure-indicating device out of contact with the revolving drum, thereby preventing a pressure record. Two types of tests were therefore made. In one type of test a disk of sufficient strength to prevent a shear was used, and in this test the time from the firing of the match head to the beginning of the pressure rise (prepressure period), and the rate and total magnitude of pressure development were obtained. In the second type of test, a disk of a thickness that would shear was used, and a record was obtained of the time from the firing of the match head to the shearing of the disk.

Results of Pressure Tests

Table 3 lists the pressure developed in the Cardox Model G shell. The pressure given is the maximum pressure developed by a given charge of heater and carbon dioxide with a disk sufficiently strong to prevent a shear. Using 100-gram heaters and charges of carbon dioxide of 570 grams and 1,135 grams, average maximum pressures of 810 and 2,860 kg./sq. cm., respectively, were produced. Using 140-gram heaters and carbon dioxide charges of 340 and 680 grams, average maximum pressures of 940 and 2,110 kg./sq. cm., respectively, were produced. With a charge of 680 grams of carbon dioxide, 100 and 140 gram heaters produced average maximum pressures of 1,380 and 2,110 kg./sq. cm., respectively.

The time determinations listed in Table 3 show wide variations in the duration of both the prepressure and pressure periods. However, the data in Table 3 and the actual pressure records clearly indicate that the larger charges of carbon dioxide appreciably lengthen the duration of the pressure period.

The time at which the disk sheared was determined on shots other than those in which pressures were determined. The averages listed are the results of three shots with each condition of charge. They indicate that in the conditions of charge tested, shearing of the disk took place before the maximum pressure was completely developed.

Three typical time-pressure records were obtained with varying charges of carbon dioxide. Curves were replotted from the original records to present them all on the same scale. A diameter of piston in the pressure-indicating device that will give the most suitable height of curve is used in testing; the original records, therefore, are not all on the same scale. The curves show the pressure record for one complete revolution of the drum, a time duration of about 0.15 second. After about one revolution, the pressure falls, due to cooling and to leakage of gas through the shell gaskets. When the disk is not sheared, the shell gaskets are almost invariably ruptured. The broken lines in the curves indicate periods in which the pencil point of the pressure-indicating device lost contact with the drum.

These curves indicate that more than half of the pressure is developed in less than 0.01 second, measuring from the beginning of the pressure rise. The two smaller charges of carbon dioxide, 570 and 680 grams, develop at least 80 per cent of their maximum pressure in 0.01 second and the largest charge, 1,135 grams, develops 80 per cent of its maximum in about 0.02 second.

Table 3.
Pressure developed within the Cardox Model G shell

Heater element, grams	Carbon dioxide Grams	Carbon dioxide Pounds	Maximum pressure Kg./sq.cm.	Maximum pressure Lb./sq.in.	Time: Prepressure period,[1] second	Time: Pressure period,[2] second	Time: Disk shear[3] second
100	570	1-1/4	750	10,700	0.021	0.060	
100	570	1-1/4	875	12,400	.007	-	
		Average	810	11,500	.014	-	-
100	680	1-1/2	1,325	18,900	.010	.032	
100	680	1-1/2	1,410	20,100	.004	.018	
100	680	1-1/2	1,400	19,900	-	-	
		Average	1,380	19,600	.007	.025	0.021[4]
100	1,135	2-1/2	2,990	42,500	.023	.090	
100	1,135	2-1/2	2,860	40,700	.016	.073	
100	1,135	2-1/2	2,740	39,000	.008	.090	
		Average	2,860	40,700	.016	.084	.025[5]
140	340	3/4	940	13,400	.005	.029	
140	340	3/4	940	13,400	.022	.030	
		Average	940	13,400	.014	.030	-
140	680	1-1/2	1,880	26,800	-	-	
140	680	1-1/2	2,140	30,500	-	-	
140	680	1-1/2	2,310	32,900	.005	.049	
		Average	2,110	30,100	-	-	.009

[1] Time from break in match head to beginning of pressure rise.
[2] Time from beginning of pressure rise to maximum pressure.
[3] Time from break in match head to shearing of disk. Average of 3 shots in which pressures were not obtained.
[4] 3.2-mm. (1/8-in.) disk.
[5] 4.8-mm. (3/16-in.)disk.

SUMMARY

As a result of this investigation the following conclusions may be drawn:

1. The propulsive strength of the Cardox blasting device Model G does not increase directly with the carbon-dioxide charge. The optimum propulsive strength may be developed by either a minimum, an intermediate, or a capacity charge, depending on the heater and disk used.

With one condition of charging, a loss of 39 per cent was noted in propulsive strength when the weight of carbon dioxide was changed from the optimum to the least effective charge.

2. In general, the propulsive strength increases with the weight of heater. With certain capacity charges of carbon dioxide, however, little difference is noted in effect of heater.

3. In all conditions tested, the propulsive strength increased with the thickness of disk.

4. The smaller grain sizes of sodium chlorate as used in the heater element were found to result in greater propulsive strength than the larger sizes.

5. Using 100-gram heaters and a nonshearable disk, the average maximum pressures developed for 570, 680, and 1,135 gram charges of carbon dioxide were 810, 1,380, and 2,860 kg./sq. cm., respectively; using 140-gram heaters, 340 and 680 gram charges of carbon dioxide gave average maximum pressures of 940 and 2,110 kg./sq. cm.

6. An increase in the charge of carbon dioxide lengthened the duration of the pressure period.

7. In the conditions tested, the data indicate that shearing of the disk took place before the pressure was completely developed.

CYCLE OF MINING WITH CARDOX

The cycle of mining with Cardox, as developed, is as follows: the face of the room or entry is first undercut with an undercutting machine for a depth of seven to nine feet, depending on the height of the seam, the type of cutting machine and the length of cutter bar used. This removes a band of coal approximately six inches thick from either the bottom, top, or at some point between the floor and roof of the coal seam. This provides another free face for the coal to break to when being dislodged and also decreases the pressure required to free the coal from the solid face.

Second, the fines, or cuttings, left in the kerf cut by the machine are removed with long-handled shovels or hooks.

Third, a number of drill holes, or shot holes, are drilled horizontally in the face and parallel to the ribs. (Figure 5). These holes are drilled, with electric drills, in two rows; one row above the other. The bottom row is placed a few inches above the band of pyrite, or bone coal, that is present in all of the No. 6 seams in Illinois.

In the lower row of holes in a room twenty-seven feet wide, the two holes nearest the rib are placed approximately twenty-four inches away from the rib and two additional holes are spaced equi-distant between these outside holes. Another row of three holes is then drilled across the upper part of the face, usually eight to ten inches below the roof; the two outer holes being about twenty-four inches from each rib. The center hole on this row is spaced midway between the outer holes. All holes above and below are drilled to a depth of six inches less than the depth of the undercut. The spacing and

DIAGRAM OF DRILLING
SCALE 1 IN. = 5 FT.

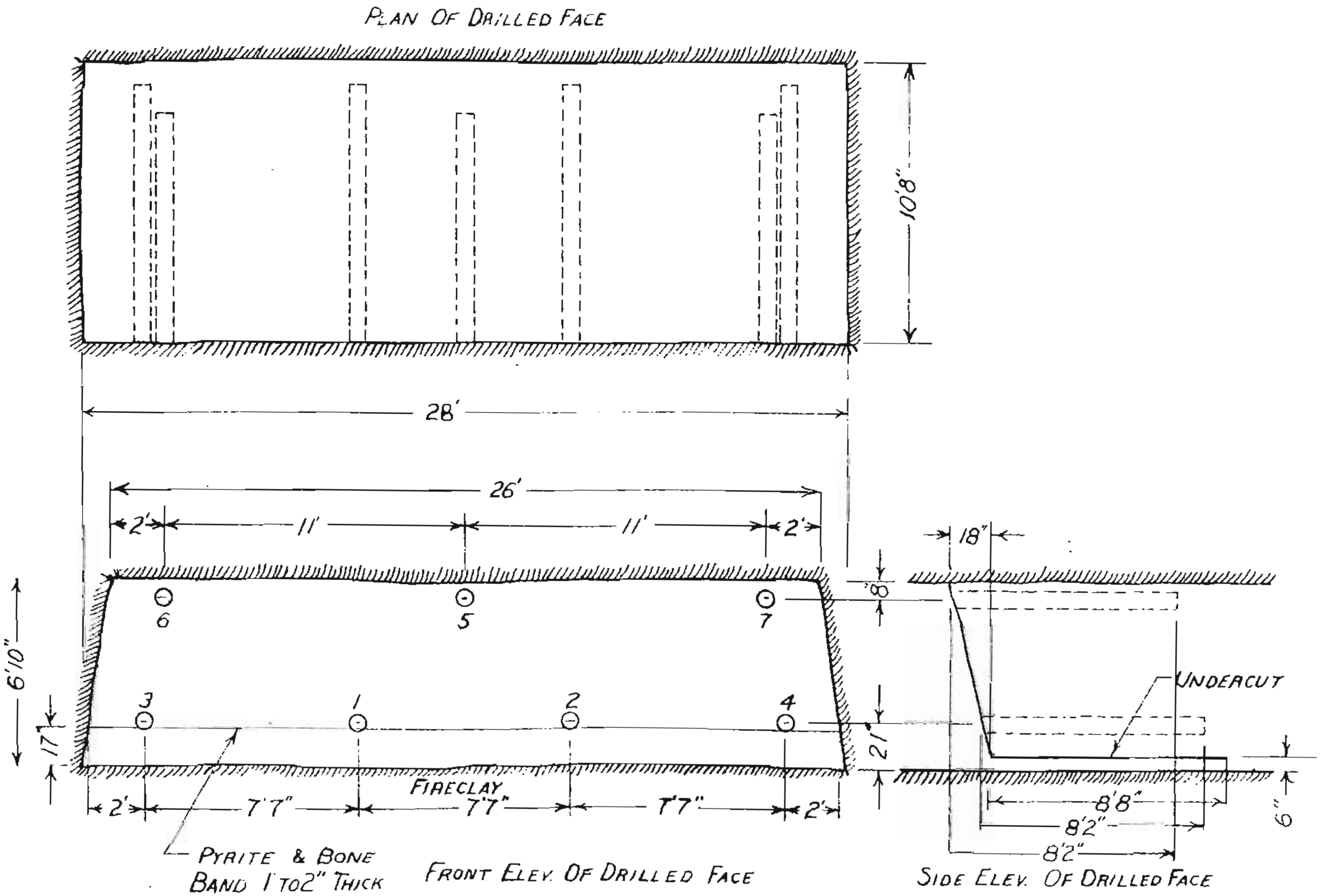
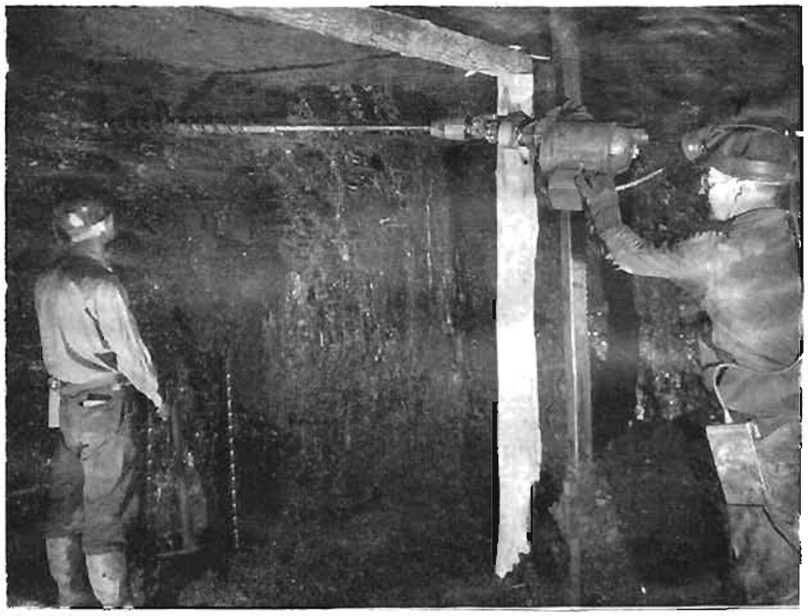
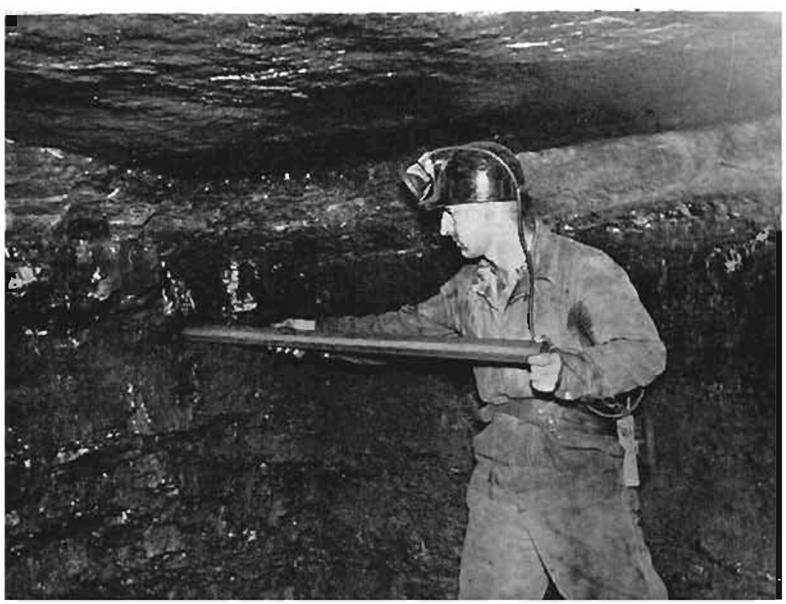


FIGURE 5



Drilling the hole for a Cardox tube.



Inserting a Cardox tube in the drill hole.
Figure 6

location of holes will vary in different mines, depending on the characteristics of the coal. However, it is very essential that the outside, or rib holes, be drilled parallel to the ribs and that the holes be drilled to a depth slightly less than the depth of the undercut to prevent the shot from being put on the "solid", or, in other words, where the advantages of the undercutting will be wasted by getting the charge in solid coal.

These holes are drilled with a portable electric, auger type, drill. (Figure 4). In some mines the drill is mounted on a post, while in others an electric hand-drill, without post, is used. The augers have detachable cutter heads, which permits removing the cutting end of the augers and replacing them as they become dulled, without having to replace the entire auger.

There are several types of cutting bits in use. Some operators prefer a one-piece "fish tail" type, while others use a type made up of four small cutter bits placed in the cutter head in such a manner as to form a flared auger shape pattern.

After the holes are drilled and all of the dust and cuttings have been removed from the hole, a Cardox cartridge is pushed to the back of each hole. An electric firing cable is connected to the small wires, or leads, attached to the firing terminals on the shell. The electric firing cable is long enough to extend from the face to break through or cross-cut, between rooms. (See Figure 5). Standing in this cross-cut to protect him from flying coal, the "shot-firer", or man who discharges the shell, discharges it by merely inserting the ends of the firing cables in terminals in a small, portable electric

The Cardox tube is inserted in the drill hole with the discharge end at the back of the hole. The electrical terminals in the head of the tube are connected to a regular shot firing cable.

Figure 7

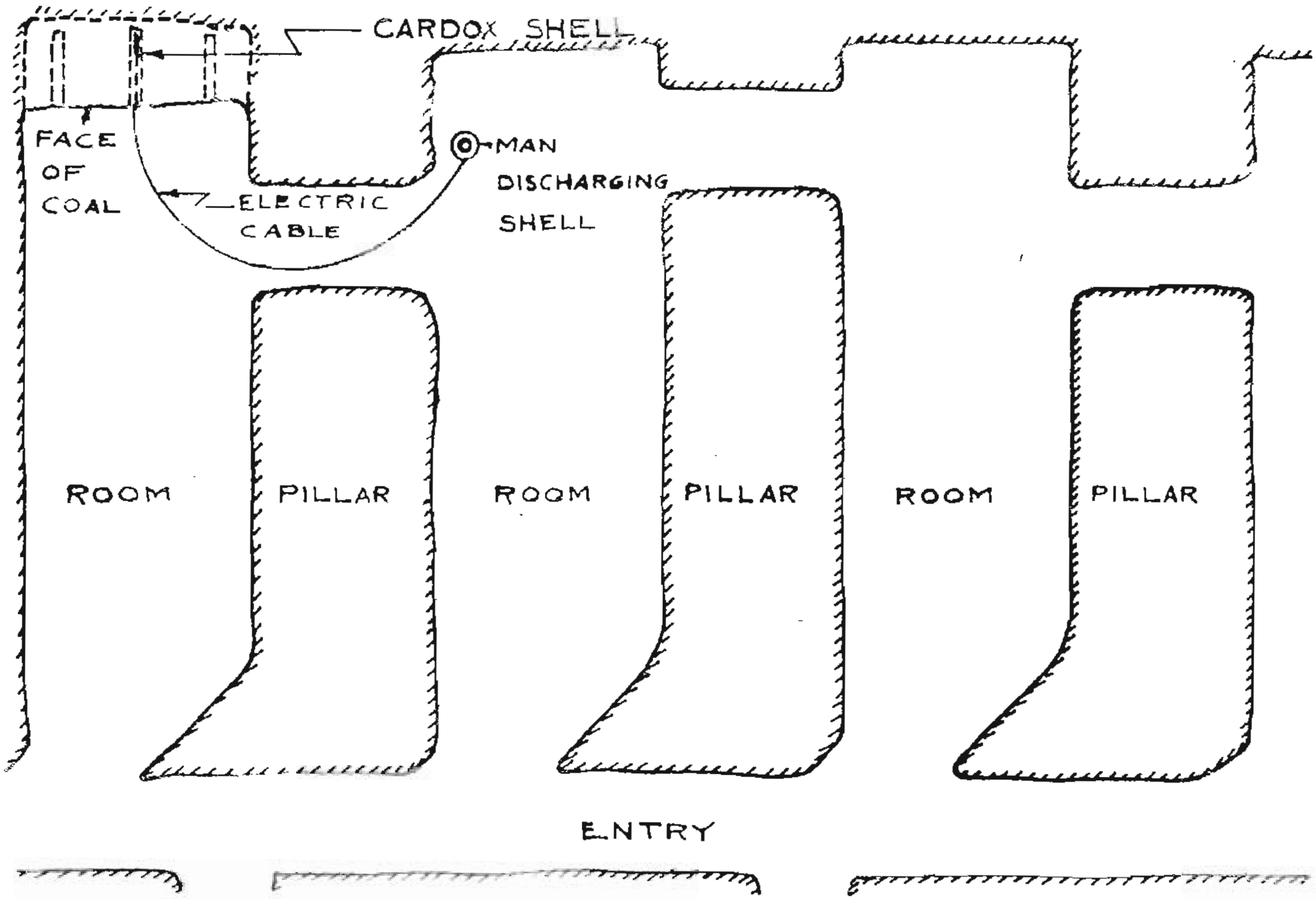
storage battery, weighing only a few pounds. The shells are discharged one at a time. As there are no noxious fumes present, the shot-firer goes back to the face after each shot, connects his firing cable to another shell and proceeds until all shots are fired. The order of firing as shown in Figure 5 is usually to shoot the two center holes on the lower row first, then each rib in the lower row, then the center hole in the upper row and finally each rib in the upper row.

In some mines after the lower holes are shot, all the coal that is broken by these shots is removed from under the coal left standing before the top holes are shot. This method provides more freedom for breaking of the upper part of the face and also causes the coal to roll free of the face, thus being much more easily loaded.

Each empty shell is picked up off the top of the coal after the shell has been discharged and placed a short way back so that it will not be covered by the coal from the next shot.

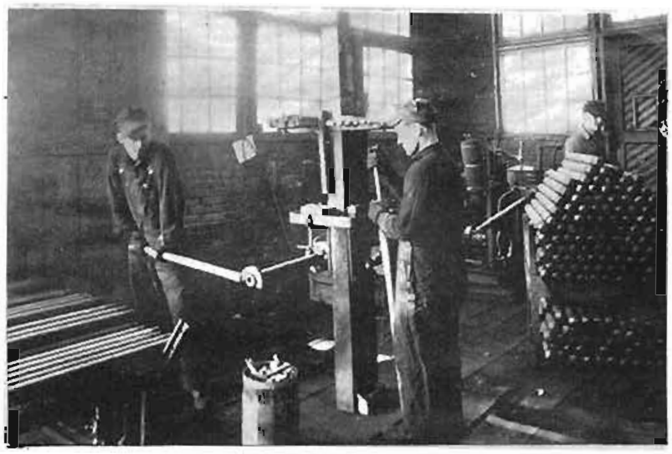
After the entire room or entry face has been broken down, all empty shells are loaded on a special truck and, along with other empty shells from that particular section, are sent either to the mine's own charging plant or sent to the surface to be picked up and taken to a central charging plant in the district for recharging. In either case, a very accurate accounting system is kept on the shells. The cost of a shell is negligible if the shell is used over and over again. However, if the shells were covered up or lost in the mine, the cost of replacing them would soon make the method expensive.

The shells and equipment are not bought outright by the mine



SKETCH SHOWING LOCATION OF SHOOTER WHEN DISCHARGING SHELL

FIGURE 8



Cardox tubes may be filled and made ready for the next shift in a small charging plant located at the mine.

Charged Cardox tubes are sent into the mine in trucks constructed for that purpose.

Figure 9

operator, but he has an option of several methods of payment; either on a basis of so much per shell, so much per ton of coal dislodged, or some such method. The basis of payment is an item decided upon by the Cardox Corporation and the mine operator. However, the mine operator is held responsible for the recovery of shells after they are discharged.

For this reason, the following system of shell accounting is in use in the Zeigler mines of the Bell and Zoller Coal and Mining Company at Zeigler, Illinois: the shells used at these mines are charged at a central charging plant owned by the Cardox Corporation, located at Benton, Illinois, a distance of fifteen miles from Zeigler. They are delivered by truck to the mine. A mine employee, the time-keeper in this case, signs a receipt for the shells received from the Cardox Company and also turns over the empty shells to the truck driver. The mine employee receives a receipt for the empty shells. This gives an accurate record of the total number of shells received and returned by the mine.

The shells are then loaded into mine cars that are made purposely for shell transportation — each truck being numbered and a record kept of the number of shells loaded into it.

A set of the various forms used in the shell accounting is included in this paper. The delivery men sign a receipt for the number of shells received by them for delivery to the various sections. (Report Form No. 108.)

When the face boss, or section foreman, finishes his shift, he makes out a form, Form No. 104, showing where and how many shells he wants delivered. This form is given to the night foreman who supervises the delivery in the entire mine. The delivery man signs a receipt for the loaded shells, Form No. 108, and delivers the loaded shells as per the order given him. He also gathers up the discharged shells at each place and makes a report on these. (Form No. 107.) The shooter, or shot-firer, also keeps a record of his shots, Form No.109, which shows how many shots were fired, how many shots were not fired, reason for not firing, bad order shells, shells recovered, etc. From all of the above reports, the time-keeper makes out a daily report on shells received, returned, number fired, etc., and sends this report to the Company office on the surface.

The section foreman also keeps a record (Form No. 111), which keeps him informed as to the number of shells delivered to him, shells returned by him and shells that have not been recovered, and for which he is responsible.

The description of this system seems rather complicated and requiring a lot of "red tape", but the actual operation of it is not so intricate. It has been found, by experience, that some such system is necessary; otherwise there would be a tremendous loss of shells, due to negligence on the part of thosehandling them. This method also gives accurate data on the tons of coal dislodged per shell used. This data is necessary in computing the cost per ton for dislodging or shooting the coal. The average for these mines is about eight tons of coal per shell.

Cardox mining can be used in any coal mine. The method may vary according to local conditions. The factors determining the methods of use are, structure and characteristics of the coal, such as cleavage, brittleness, height, presence of and character of bands of impurities in seam, method of cutting and loading, roof conditions (Cardox minimizes roof breakage), labor conditions, state laws and the results desired by the mine operator. The particular method for any mine is determined by actual tests made by experienced engineers of the Cardox Corporation in the mine in which it is to be used.

As a matter of interest, it might be well at this point to tell something of the development and experimentation with carbon dioxide for dislodging coal. The Cardox tube has undergone a progressive series of developments which have simplified its use, increased its efficiency and broadened its range of practical application.

The original tube weighed over ninety pounds and contained over fifty parts. Special drilling equipment was necessary and a 75-ampere current at high voltage was required to pperate the heating element. This tube discharged at internal pressures ranging from 20,000 to 40,000 pounds per square inch. The discharge parts were also constructed at right angles to the longitudinal axis of the shell.

The original charging plant, which was located underground at the No. 5 mine of the Centralia Coal Company at Centralia, Illinois, was an intricate plant. The gas was received as a gas and in order to liquify the carbon dioxide, there was an ordinary, commercial type electric refrigerator installed in which great coils of tubing were placed so that the temperature of the gas could be lowered. Then with a tremendous pressure applied on the gas at a very low temperature, by a rather bulky compressor, the gas was liquified and pumped into the shells. They were then hauled into the working places without much thought being given to accounting.

After the shells were charged, the first thing to be determined for this method of mining was the proper location and number of the shells throughout the face to give the desired results, which were, complete dislodging of the coal with a minimum of fine coal, without having chunks too large to be loaded with the loading machine.

We tried various locations for the shells in the coal face. Our assumption at first was that the force of the discharge would be expended equally in all directions, but we found, by trial, that there was very little breakage above the shell or on the side away from the undercut portion of the face. From this knowledge evolved the present system of placing the top and outer holes very close to the height desired and not too far from the ribs.

In order to reduce the labor involved, we attempted to drill all the holes in the face by setting the drill only at two different locations and drilling our holes radially from these two locations. We found that this was not the proper method, as the perpendicular distance from the face to the back of the hole could not be determined accurately and many holes were "over-drilled", then the shell would be discharged on the "solid", that is, in a portion of the coal that had not been undercut. We found that this caused one of two things — the shell, upon being discharged, would either "fly" out of the hole without dislodging any coal, or it would break the entire face down in one or two enormous chunks that would have to be broken up with sledge and wedge before it could be loaded. From this we learned that it would be necessary to drill all the holes level and parallel to the ribs of each working place. We found that by placing the holes in this manner there was very little damage to a weak roof, the coal was broken uniformly and the shells did not fly out of the holes.

Due to the large diameter of the shell, it was necessary to have special drilling equipment. The drills were made of heavy tubing, with a steel bar 3/8" x 3/8" spiraled around the tubing to pull the cuttings out of the hole. The head was a sleeve type fitting, with a tooth-like contour on one end. These teeth were hard surfaced with a hard alloy and the head was screwed onto the end of the tube serving as the drill.

The electric drill motor was heavy and was mounted on a drill post that stood vertical and was held in place by being wedged between floor and roof by means of a jack screw on the lower end. The drill stems were detachable from the drill motor.

From our experience in blasting with permissable explosives, we thought it would be necessary, after the shell was inserted in the hole, to tamp the remaining part of the drill hole full of fire clay to confine the explosive force to the back of the hole. Therefore, our original equipment consisted of a small portable compressor which was used to operate a small, portable ram to tamp fire clay into each hole after it was loaded.

We learned by experimentation that if the holes were properly drilled, as explained above, it was not necessary to "tamp the shots" to any great extent, therefore the portable compressor and tamping ram were discarded. We next tried out a mechanical tamping, which was a cylindrical steel plug split longitudinally and having the outer edges made with a surface such as a rasp. This plug was inserted in the outer end of the hole with a wedge between the two halves, the idea being that the force of the discharge would momentarily tighten it in the hole and confine the force, causing it to work through the coal. This did not prove successful and was soon discarded.

After all holes were drilled and loaded, the shells were discharged, one at a time, as they are at present, but by a much more cumbersome method. The original heater elements in the shells required around seventy-five amperes at quite a high voltage to ignite them. Due to this amperage, the firing cable had to be fairly large, and also due to the high amperage and voltage, the only source of electricity to energize the heater was the trolley wire in the mine entry, As the shots were in rooms, the face of which were sometimes one hundred fifty feet from the trolley wire, it was necessary to have a cable one hundred twenty-five to two hundred feet long. This cable was very heavy and cumbersome, as well as very expensive, and required considerable time to move from place to place. Also, as the source of electric energy was the trolley wire on the entry, quite a lot of time was required for the man discharging the shells to walk back and forth from the coal face to the entry during the process of discharging all the shells.

By constant research and experimentation, and by different ideas evolving from actual results, the present equipment and methods have been developed. In the development of the Cardox system of mining, we kept in mind the safety feature of the system, as well as the production feature. By using carbon dioxide for the breaking down of the coal with the absence of flame, nöxious gases or fumes there is an inherent safety feature in this method, but it was learned by actual practice that certain precautions must be taken to reduce accidents to men in using Cardox. After working on the development of Cardox shooting, the following rules were formulated for the safety of men and mines in using Cardox blasting. These rules are all based on experience:

SAFETY RULES FOR CARDOX

1. Wherever possible, CARDOX shall be handled to and from the charging plant to the working sections of the mine in insulated mine cars or in removable containers that can be placed in mine cars. No one shall ride in cars containing CARDOX tubes.

2. Wherever practical, CARDOX tubes shall be placed in the bore hole before lead wires are attached. No tubes shall be moved, carried or transported from place to place if the lead wires are attached, except that the shot firer actually at the face shall carry them with leads shunted from the point of wiring to the bore hole.

3. No CARDOX tube shall be wired at the face while any electrical equipment is at or near the face. Care should be used to avoid wiring tubes adjacent to the mine track.

4. After tubes are wired, the leads shall be shunted by twisting the ends of the wire together. This connection shall not be broken except when ready to connect shooting cable. Tubes that have been wired but not used in a place shall have lead wires removed before being taken to another place for use.

5. All protruding nails (if used) and all wire should be removed from all tubes, whether good discharges or misfires, before they are removed from the face for return delivery to the charging plant.

6. Shotfirer shall have a minimum length of 125' of well insulated cable, and shall keep battery ends twisted together and shunted except at the moment of actual firing. Wherever possible, the cable shall not be left strung out in the place while making successive shots, but shall be rolled up, and taken to the face between each shot. This rule may be changed by local custom or mining conditions, or if a helper remains at the battery end of the cable while successive shots are being connected.

7. CARDOX tubes will fly out of the bore hole if the shot is overburdened, or if the hole is on the solid. No danger of an explosion or an ignition exists in case of such a blown-out tube, but

the danger of a flying missile is present. Avoid danger by being in the clear and in a safe place.

8. When ready to shoot, all men in the area adjacent to the place being shot, shall be properly notified, and everyone shall be in the clear and preferably around two ninety degree corners from the place being shot, and at sufficient distance from the face being shot. The shotfirer shall call FIRE three times before discharging the shot.

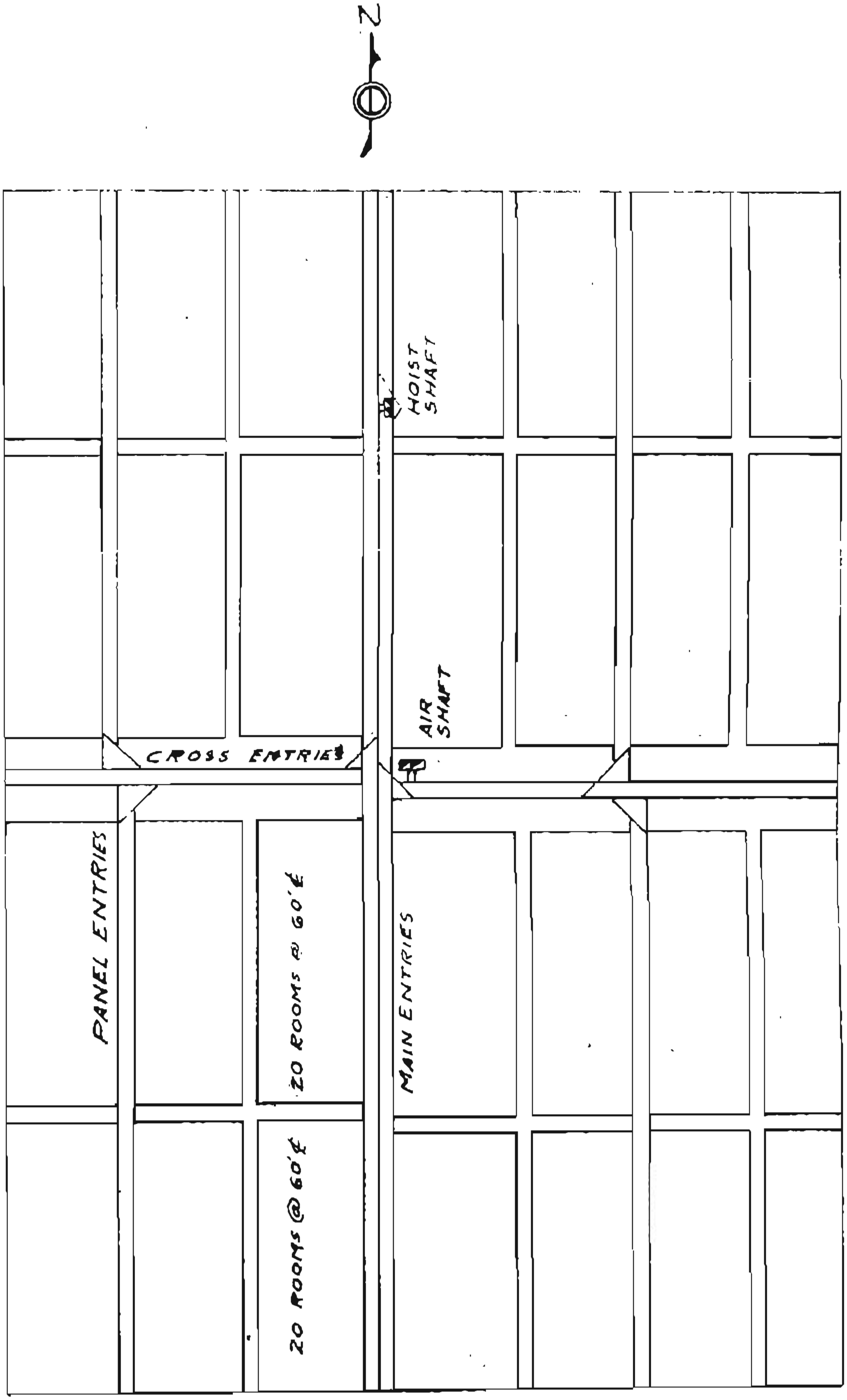
9. In case a CARDOX tube fails to discharge, the shotfirer shall wait five minutes before returning to the face to examine the tube. If no defect in the wiring is apparent and upon a second trial the tube fails to discharge, after the proper waiting period, this cartridge should be removed from the bore hole and another cartridge substituted. The wires should immediately be removed from the bad order CARDOX tube and the tube marked as a misfire.

10. It shall be the duty of the shotfirer to carefully examine all holes before charging them, and no hole should be fired unless it clears the undercut.

11. Best results are usually obtained in using CARDOX if after the tube is placed in the bore hole and pushed to the back, the tube is withdrawn from four to six inches, depending on conditions and experience in a given seam of coal.

12. CARDOX can be very effectively used for fighting incipient fires, and fire bosses, shotfirers and all officials should be made familiar with the use of CARDOX tubes for this purpose. Wrenches for the release of the carbon dioxide gas should be placed at each loaded tube station in the various mines.

The mine layout for using Cardox mining, as used at the Number 5 mine of Centralia Coal Company (see Figure 10) is the same layout that was used for mining with permissible explosives. This system is the panel system, With all entries twelve feet wide and on fifty-two foot centers. The main north and south entries are driven in triplicate with rooms driven at ninety degrees to the first and third entry. Cross entries go east and west off the main entries and panel entries are driven north and south off the cross entries. All rooms off the panel entries go east and west and are driven twenty-six feet wide and to a depth of



SKETCH OF MINE LAYOUT FOR CARDOX

FIGURE 10

either three hundred fifty feet or four hundred two feet, depending on their location. All rooms are on sixty-foot centers.

Panel entries are "staggered" on each side of cross entries so that the roof will not be weakened in one continuous line across the mine. A barrier pillar is left between the cross entry and the first entry to prevent any general roof movement or "squeeze" from coming onto the cross entry. A barrier pillar of fifty-two feet is also left between faces of abutting rooms to prevent a "squeeze" in one territory from moving over into the adjoining one.

One of each pair of entries is always driven fifty feet at forty-five degrees to the entry from which it is driven. This permits laying the mine track on a smooth curve going into an entry. Haulage track is laid in the main north and south and east and west cross entries that is sixty pound steel; in the panel entries, of thirty pound steel; and in rooms, twenty-five pound steel is used. All rails are placed on treated wooden ties on forty-two inch gauge.

All coal is loaded with crawler type loading machines into three-ton steel cars which are moved with electric locomotives.

SUMMARY

The use of carbon dioxide for dislodging coal is very successful, as it provides a method that is safe, that permits economical operation and produces coal of such a grade, as to size, to cause a greater realization on the sale price of the coal.

The results of and advantages of the use of Cardox are:

There are no noxious fumes, smoke, flame or explosions. This eliminates any danger to the men from such results that so often occur with explosives. Since there is an absence of the undesirable fumes, smoke and explosions, it is safe and advantageous to break down a face of coal as soon as it is prepared, without having to wait until the end of the shift when all the men are out of the mine.[1]

The advantage of being permitted to break down the coal at any time during the working shift is a tremendous help toward economical operation. If a "fall" of coal can be loaded from a working place, then that same place be prepared and broken down and loaded again during the same shift, the total number of working places required to keep machines and crew busy for the entire shift is at a minimum. This is economical, because:

First, it requires less material, such as track, trolley, dead work, etc., for a territory.

---

[1] This advantage is eliminated in some states by state laws that prohibit the dislodging of coal by any method while men are in the mine. In most cases where such laws exist, the inclusion of Cardox is the result of the influence of labor trying to prevent a reduction in the working force.

Second, less time is lost in moving loading machinery short distances from place to place.

Third, it permits concentration of the entire force of men employed on each territory, which allows closer supervision and tends to increase production and enforce safe mining practices.

Fourth, such concentration of mining decreases the cost of ventilation and of delivering material.

Fifth, the concentration of operations requires less development of entries that have to be kept open and maintained over a long period of time. With Cardox mining, the development may be carried along by the same crew that operates in the rooms on the panel system.

Sixth, electrical power supply transportation and maintenance of main line haulage ways are simplified by concentrated mining made possible by the use of carbon dioxide for dislodging the coal.

Roof conditions and roof control are two of the major factors governing coal mining, both from an economical and safety standpoint. Coal output is limited by roof conditions. Due to the slow, heaving action of Cardox, the roof is not subjected to the hard, quick, hammer-like blow of an explosion. This prevents disturbance of the roof and consequently, eliminates falls of rock or slate that are costly to clean up, dangerous for men to work around, and which retard productive operation.

When using Cardox, a room or entry may be worked to the boundary and abandoned quickly. Because of this, the roof does not have to be supported for a long period of time, thus the expense and hazard of maintaining the roof is reduced to a minimum and accidents from roof falls are reduced. This condition eliminates retimbering, as is often necessary in places that have to be kept open for a long period of time.

Cardox preserves the coal structure, reduces the percentage of fines and therefore increases the realization. The discharge of Cardox is a simple expansion of combined gases, producing a slow, pushing action.

The maximum pressure developed by Cardox is much less than that developed by explosives -- about one-third that of black powder, and one-sixth that of permissibles. The duration of application, however, is very dangerous, because the carbon dioxide continues to expand and does not reach its maximum volume until all of its force has been spent.

It is this slow heaving, spreading, and shearing action that breaks the coal along its natural lines of cleavage, rolls it forward for quick, easy loading, and largely eliminates the minute shatter cracks that cause excess degradation.

As coal mined with Cardox has a minimum of shatter cracks, there is a maximum of coarse sizes free from structural weakness. The lumps do not crumble or disintegrate to as great an extent as coal mined with explosives.

The result stated above is highly desirable as it increases the price of realization on the coal, reduces the small sizes that are hard to dispose of on the market, and increases the larger sizes that are more in demand.

On the following page is a reprint of the results of a three months' test of Cardox at the Standard Coal Company in Utah, and submitted in a paper before the American Mining Congress by Mr. R. R. Kirkpatrick, Superintendent of the Standard Coal Company. This was published in the Coal Mine Mechanization Year Book of the American Mining Congress of 1935, on page 79.

"The three month run with Cardox showed a considerable increase in large coal and a marked improvement in the quality of the stove and lump. I quote figures obtained from an extended test showing comparison of breaking percentages and sales realization of powder and Cardox shot coal which may be interesting ...."

Table 4

POWDER SHOT COAL

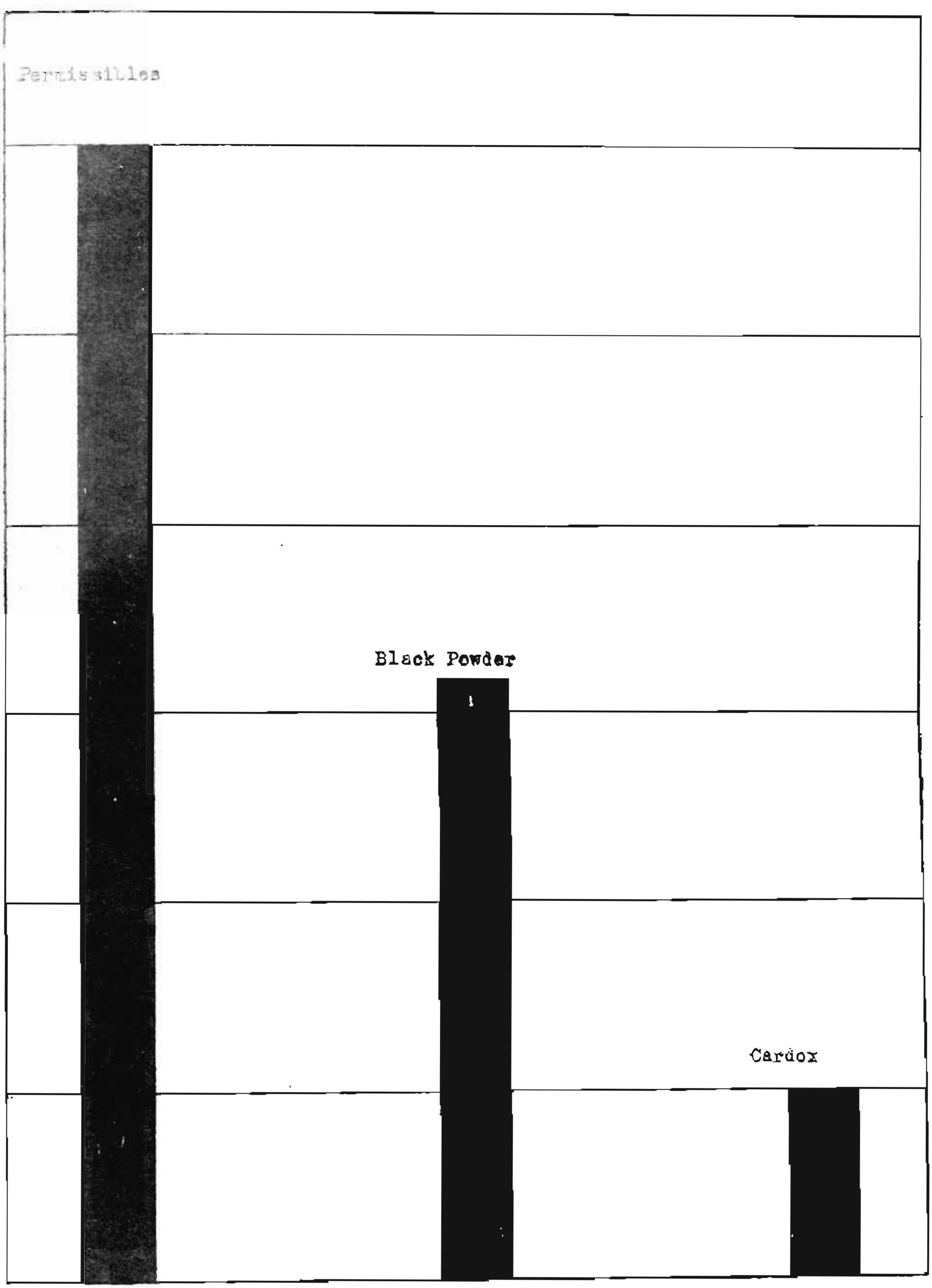
Classification	Breaking percentage	Sales price	Sales Realization
Lump, 8-inch plus	18.2	$3.75	$.6825
Stove, 3-inch by 8-inch	26.3	3.40	.8942
Nut, 1 5/8-inch by 3-inch	16.2	2.75	.4455
Slack, 1 5/8-inch minus	39.3	1.50	.5895
Totals	100.0		$2.6117

CARDOX SHOT COAL

Classification	Breaking percentage	Sales price	Sales Realization
Lump, 8-inch plus	31.1	$3.75	$1.1663
Stove, 3-inch by 8-inch	24.6	3.40	.8364
Nut, 1 5/8-inch by 3-inch	12.1	2.75	.3327
Slack, 1 5/8-inch minus	32.2	1.50	.4830
Totals	100.0		$2.8184

The results of using Cardox for mining coal all tend to make coal mining safer and more profitable. A successful mining operation might be defined as one that makes a maximum profit, with a minimum of danger to men and mine. Therefore, the use of carbon dioxide for dislodging coal can be said to contribute to successful coal mining.

CHART SHOWING RELATIVE DISCHARGE PRESSURES OF CARDOX,
BLACK POWDER & PERMISSIBLE EXPLOSIVES



RELATIVE DISCHARGE PRESSURES
Figure 11

View showing coal dislodged by Cardox
blasting method.

Figure 12

B2-94

DAILY REPORT OF SHELLS USED

Joy Number	Rec'd	Shells Sent Out	B. O.	Number Shells Fired	Joy Number	Rec'd	Shells Sent Out	B. O.	Number Shells Fired
Joy 1					Joy 15				
Joy 2					Joy 16				
Joy 3					Joy 17				
Joy 4					Joy 18				
Joy 5					Joy 19				
Joy 6					Joy 20				
Joy 7									
Joy 8					Total				
Joy 9									
Joy 10					Shells Available for Del'y.				
Joy 11					Shells Delivered				
Joy 12					Bal.				
Joy 13					Shells Over in Del'y.				
Joy 14					Shells Short in Del'y.				
					Shells on Hand After Delivery				
Date—					per—				

Form No. 94

Figure 13

BZ 104

SHELL REPORT

	Loads		Empties		On Hand	
Room No.	Ord.	Del.	Shot	Out	Emp.	Loads

Unit　　　　　　　　　　Boss

Form No. 104

Figure 14

BZ 107

NIGHT BOSS' REPORT
ON EMPTY SHELLS BROUGHT TO BOTTOM

______________________19 ___

Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Truck No.	Unit No.
Total	

____
Night Boss

Form No. 107

Figure 15

B.Z. 108

SHELL MEN'S RECEIPT
FOR LOADED SHELLS

_______________19 ___

Received for delivery Loaded Shells as follows:

Truck No.

Truck No.

Truck No.

Truck No.

Truck No.

Truck No.

Truck No.

Truck No.

Truck No.

Truck No.

Total..

____
Shell Man

____
Shell Man

Form No. 108

Figure 16

SHOOTER'S DAILY REPORT OF CARDOX SHOOTING

MINE NO.____________ UNIT NO.____________ DATE________________19___

LOCATION	SHOTS				SHOTS NOT FIRED	REASONS FOR SHOTS NOT FIRED	EXTRA SHELLS USED	SHELLS RECOVERED	SHELLS NOT RECOVERED	REASONS FOR SHELLS NOT RECOVERED
	GOOD SHELLS	HOT SHELLS	B. O. SHELLS	TOTAL						
TOTAL										

REMARKS:____

SIGNED________________________

Form No. 109

Figure 17

BZ 111

FACE BOSSES DAILY SHELL REPORT

UNIT NO._____ LOCATION ______________________________ ____________________19 ___

ROOM OR ENTRY																									TOTALS
1. Lost shells at beginning of shift																									
2. Shells available																									
3. Shells delivered by night crew																									
4. Shells brought into place from another place																									
5. Total shells in place during shift																									
6. Shells fired																									
7. Shells bad orders																									
8. Shells sent out																									
9. Shells taken from place to some other place																									
10. Total shells taken from place during shift																									
11 = 5 — 10 Total shells in place at end of shift																									
12. Lost shells beginning of shift																									
13. Shells lost in last night's shooting																									
14. Total lost shells																									
15. Shells recovered today																									
16. Lost shells on hand at end of shift																									

NOTE:—Line 1 Today Same as Line 16 Previous Day. Line 2 Today Difference Between Line 11 and Line 16 Previous Day. Line 12 Today Same as Line 1.

REMARKS:

Form No. 111
Figure 18

BIBLIOGRAPHY

1. Report of Investigations, Number 3084, Department of Commerce - United States Bureau of Mines, April, 1931.

2. Yearbook of the American Mining Congress, 1935.

VITA.

Durward Rice Schooler was born at Columbia, Missouri, on May 12, 1895. He attended the City schools and graduated from Columbia High School in 1915. He then attended the University of Missouri for one year and was employed for the next four years in the Engineering Department of the Bell & Zoller Mining Co. at Zeigler, Illinois.

In 1922, he entered the Missouri School of Mines and Metallurgy and was graduated with a B.S. in Mining in 1926. Immediately after graduation he was employed as a mine foreman by the Union Colliery Company at Dowell, Illinois, but later returned to the Bell & Zoller Coal and Mining Company in southern Illinois as mining engineer. In 1929, he became chief mining engineer for the Centralia Coal Company, Centralia, Illinois (a subsidiary of the Bell & Zoller Company). It was during the period from 1928 to 1932 that he assisted in the development of Cardox at Centralia and Zeigler, Illinois.

He was made superintendent of the No. 5 mine of the Centralia Coal Company at Centralia, Illinois in 1935, which position he held until September, 1942, when he returned to Missouri School of Mines as assistant professor of Engineering Drawing, the position he holds at the present time.

INDEX